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(54) Title: IMPROVED CORED ELECTRODE WIRES

(57) Abstract

A cored electrode wire for pulsed electric arc welding, wherein said core includes from 2.5 to 12% calcium fluoride, from 2 to 8% calcium carbonate, from 0.2 to 2% silicon dioxide and from 0.5 to 1.5% of a fused mixed oxide. Also disclosed is a cored electrode wire for pulsed electric arc welding, wherein said core contains from 4 to 15% elemental manganese and from 2 to 8% elemental silicon, the remainder of the core comprising fused mixed oxide, desired alloying components and iron powder. In each of the above cases, the wire is suitable for use with the following welding pulse parameters: pulse energy: 8 to 250 J and preferably 10 to 120 J; pulse frequency: 10 to 500 Hz and preferably 15 to 350 Hz; background current: 8 to 250 A and preferably 10 to 100 A; wire feed speed: 1 to 20 m/min and preferably 4 to 17 m/min.

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TITLE: IMPROVED CORED ELECTRODE WIRES

Field of the Invention:

This invention relates to cored electrode wires for pulsed electric arc welding and to a pulsed electric arc welding method utilising same.

Background of the Invention:

Solid electrode wire generally suffers from lack of versatility in alloy composition, since only large batches are economical, and absence of the protective and cleaning action provided by a slag. In addition, the solid wire/ conventional power supply combination can give problems with lack of sidewall fusion in joining thicker sections.

Cored wires offer great versatility with regard to alloy composition since alloy additions are made via the core. They also generally give better sidewall fusion than solid wires. To reliably achieve the good low temperature impact properties and low weld metal hydrogen levels required in certain cases, basic-flux cored or metal cored wires demonstrate considerable advantage compared to alternative slag systems such as rutile ones.

However, the combination of basic cored wire with conventional power supply gives harsh welding operation, can be used only in a narrow range of welding currents, and is not usable for positional welding. The combination of basic cored wire with pulsed power supply, on the other hand, has been found to give good welding behaviour over a wide range of welding currents and to offer an all-position welding capability. Similarly, metal cored wires are only usable at high currents with conventional power supply but, when combined with pulsed power supply give good welding behaviour over a wide range of welding currents and offer all-position welding capability.

Summary of Invention and Objects:

It is therefore an object of a first aspect of the present invention to provide cored electrode wires which are suitable for use with pulsed electric arc welding programs, and to provide a range of programmes suitable for use therewith.

In a first aspect, the invention provides a basic flux cored electrode wire for pulsed electric arc welding, characterised in that the slag forming components contained in the core of said electrode wire are of a lower level than the slag forming components which must be contained in a basic flux cored wire suitable for normal arc welding.

In a preferred form of the first aspect of the invention, the core includes from 2.5 to 12% calcium fluoride, from 2 to 8% calcium carbonate, from 0.2 to 2% silicon dioxide and from 0.5 to 1.5% of a fused mixed oxide.

In a particularly preferred form of the invention, the core includes from 2.5 to 8% calcium fluoride, from 2 to 6% calcium carbonate, from 0.2 to 1% silicon dioxide and from 0.75 to 1.25% fused mixed oxide. In one form, the fused mixed oxide may contain approximately 10% MgO, 15% MnO, 10% Al_2O_3, 5% CaO, 60% SiO_2.

The above defined electrode is suitable for pulsed arc welding with the following pulse parameters:

Pulse Energy	8 to 250 J and preferably 10 to 120 J
Pulse Frequency	10 to 500 Hz and preferably 15 to 350 Hz
Background Current	8 to 250 A and preferably 10 to 100 A
Wire Feed Speed	1 to 20 m/min and preferably 4 to 17 m/min

In a presently preferred form of the invention, the core may have the following composition and is suitable for use with a pulsed electric arc welding program having the following pulse parameters:

<u>Wire Diameters</u> 0.9 to 1.8 mm

<u>Shielding Gas</u> Argon-carbon dioxide mixtures containing 2 to 25% CO_2 and, in some cases, up to 3% O_2.

<u>Proportion of core</u> - 15 to 28% of total wire weight may be core
- preferably 18 to 25% of core
- specifically 23% core for 1.6mm dia wires and 21% for 1.2mm dia wires.

Core Composition

	%age of Core	
	Broad Range	Preferred Range
Source of elemental Mn (such as silicomanganese or manganese)	3 to 12 (as Mn)	5 to 9
Source of elemental Si (such as silicomanganese or ferrosilicon)	2 to 7 (as Si)	2 to 5
Calcium fluoride (may be in mineral form)	2.5 to 12	2.5 to 8
Calcium carbonate (may be in mineral form)	2 to 8	2 to 6
Silicon dioxide (may be in mineral form,	0.2 to 2	0.2 to 1
Fused mixed oxide (Containing approximately 10% MgO, 15% MnO, 10% Al_2O_3, 5% CaO, 60% SiO_2)	0.5 to 1.5	.75 to 1.25
Source of elemental Cr (such as chromium or ferrochromium)	0 to 1.5	depends on alloy required
Source of Ni (such as nickel powder)	0 to 15	depends on alloy required
Source of Mo (such as ferromolybdenum)	0 to 5	depends on alloy required
Source of Ti (such as ferrotitanium)	0 to 1.5 (as Ti)	0 to 0.8
Source of B (such as ferroboron)	0 to .045 (as B)	0 to .033
Iron powder	remainder	remainder

Pulse Parameters

	Range
Pulse width (ms)	2 to 6
Peak current (A)	400 to 550
Minimum Pulse Frequency (Hz)	15 to 80

Maximum Pulse Frequency (Hz)	120 to 300
Minimum Background Current (A)	15 to 50
Maximum Background Current (A)	15 to 80
Minimum Wire Speed (m/min)	1.56 to 4.55
Maximum Wire Speed (m/min)	6.50 to 16.90

The specific combination of parameters needs to be optimized for each specific wire.

In a second aspect, the invention provides a method of operating a pulsed electric arc welding apparatus using a cored electrode wire having a basic core composition comprising the steps of adjusting the parameters of the pulse program of the apparatus in accordance with the following:

Pulse Energy	8 to 250 J and preferably 10 to 120 J
Pulse Frequency	10 to 500 Hz and preferably 15 to 350 Hz
Background Current	8 to 250 A and preferably 10 to 100 A
Wire Feed Speed	1 to 20 m/min and preferably 4 to 17 m/min

More specifically, the following parameters may be used:

<u>Pulse Parameters</u>	<u>Range</u>
Pulse width (ms)	2 to 6
Peak current (A)	400 to 550
Minimum Pulse Frequency (Hz)	15 to 80
Maximum Pulse Frequency (Hz)	120 to 300
Minimum Background Current (A)	15 to 50
Maximum Background Current (A)	15 to 80
Minimum Wire Speed (m/min)	1.56 to 4.55
Maximum Wire Speed (m/min)	6.50 to 16.90

In a particularly preferred form of this aspect, the core composition of the electrode wire is in accordance with the definition of the first aspect of the invention appearing above.

In a third aspect of the invention, the invention provides a cored electrode wire for use with pulsed electric arc welding, characterised in that the core contains a metal powder composition having less manganese and silicon than would be required for a cored wire for use with normal

electric arc welding.

It will be appreciated that the inclusion of manganese and silicon in a cored wire for use with normal electric arc welding influences the running characteristics and bead shape of the weld metal. If insufficient manganese and silicon are included in the core, the bead shape will be poor and the resulting weld will have inferior mechanical properties. By using a cored wire in conjunction with a pulsed electric arc welding program, the present inventors have found that less manganese and silicon may be included in the core without adversely affecting the bead shape or running characteristics, thereby resulting in superior mechanical properties in the resultant weld.

In a preferred form of this aspect of the invention, the core contains from 4 to 15%, and preferably 6 to 10% of elemental manganese and from 2 to 8% and preferably from 2.5 to 5% elemental silicon.

The above electrode is suitable for pulsed arc welding with the following pulse parameters:

Pulse Energy	8 to 250 J and preferably 10 to 120 J
Pulse Frequency	10 to 500 Hz and preferably 15 to 350 Hz
Background Current	8 to 250 A and preferably 10 to 100 A
Wire Feed Speed	1 to 20 m/min and preferably 4 to 17 m/min

In a particularly preferred form of this aspect, the core composition is as defined below and the pulse parameters of the pulsed electric arc welding program suitable for use with the cored wire are as follows:

Wire Diameters 0.9. to 1.8 mm

Shielding Gas Argon-carbon dioxide mixtures containing 2 to 25% CO_2 and, in some cases, up to 3% O_2.

Proportion of core - 15 to 25% of total wire weight may be core
- preferably 17 to 23% of core
- specifically 21% core for 1.6mm dia wires and 1.2mm dia wires.

Core Composition

	%age of Core	
	Broad Range	Preferred Range
Source of elemental Mn (such as manganese powder or ferromanganese)	4 to 12 (as Mn)	6 to 10
Source of elemental Si (such as silicon powder or ferrosilicon)	2 to 8 (as Si)	2.5 to 5
Source of Ti (such as ferrotitanium)	0 to 1 (as Ti)	0.2 to 0.5
Fused mixed oxide (Containing approximately 10% MgO, 15% MnO, 10% Al_2O_3, 5% CaO, 60% SiO_2)	0 to 1.5	0.2 to 1.0
Source of B (such as ferroboron)	0 to 0.05 (as B)	0.005 to .05 (as B)
Source of elemental Cr (such as chromium or ferrochromium)	0 to 2	depends on alloy required
Source of Ni (such as nickel powder)	0 to 20	depends on alloy required
Source of Mo (such as ferromolybenum	0 to 5	depends on alloy required
Iron powder	remainder	remainder

Pulse Parameters

	Range
Pulse width (ms)	2 to 6
Peak current (A)	350 to 550
Minimum Pulse Frequency (Hz)	25 to 100
Maximum Pulse Frequency (Hz.	120 to 350
Minimum Background Current (A)	10 to 50
Maximum Background Current (A)	20 to 100
Minimum Wire Speed (m/min)	1.26 to 3.78
Maximum Wire Speed (m/min)	5.20 to 15.60

Th specific combination of parameters needs to be optimized for each specific wire.

In a fourth aspect of the present invention, there is provided a method of pulsed electric arc welding utilising a cored electrode wire containing a metallic core, characterised in that the electric arc welding apparatus is programmed with the following pulse parameters:

Pulse Energy	8 to 250 J and preferably 10 to 120 J
Pulse Frequency	10 to 500 Hz and preferably 15 to 350 Hz
Background Current	8 to 250 A and preferably 10 to 100 A
Wire Feed Speed	1 to 20 m/min and preferably 4 to 17 m/min

More specifically, the following parameters may be used:

Pulse Parameters	Range
Pulse width (ms)	2 to 6
Peak current (A)	350 to 550
Minimum Pulse Frequency (Hz)	25 to 100
Maximum Pulse Frequency (Hz)	120 to 350
Minimum Background Current (A)	10 to 50
Maximum Background Current (A)	20 to 100
Minimum Wire Speed (m/min)	1.26 to 3.78
Maximum Wire Speed (m/min)	5.20 to 15.60

Brief Description of the Drawings:

Figure 1 is a graph showing the variation of deposition rate with welding current for a basic cored wire/pulsed welding process embodying the invention compared to that normally obtained from a non-pulsed commercially available basic cored wire;

Figure 2 is a graphical summary of yield strength and Charpy impact results obtained from wires embodying the invention;

Figure 3 is a graph showing the variation of deposition rate with welding current for a metal cored wire/pulsed welding process embodying th invention compared with a conventional metal cored wire using non-pulsed welding.

Description of Preferred Embodiments:

Several preferred embodiments of each of the above

aspects of the invention will now be described in greater detail. The examples of preferred embodiments of the basic cored electrode wire resulted from substantial experimentation.

The welding power supply used was a Welding Industries of Australia CDT Pulse Welder. A personal computer was attached, via a serial link, to the pulse program storage area of the power supply controls. This allowed any of the ten pulse parameters in the pulse programme being used to be altered at will. A commercial package would include supply of an EPROM for installation into the CDT pulse welder or other pulse welder, with the optimum pulse program for a specific wire.

<u>Example 1</u> - Basic wire-pulse combinations for joining HY80 steel.

One of the early experimental wires of 1.6mm diameter was chosen and an exercise undertaken to find a combination of pulse parameters which gave optimum operating behaviour over a wide current range. This resulted in a pulse program which gave good welding behaviour, a flat to slightly convex fillet shape and very little spatter over the welding current range 130 to 350A. Furthermore, the lower end of this range (about 130 to 150A) could be used for positional welding with slightly convex but acceptable vertical and overhead stringer beads being achievable. Weave techniques allowed the production of good profile positional fillet welds.

Measurements were made of the variation of deposition rate and efficiency with welding current using a representative wire and pulse program. The deposition rate results, together with those obtained previously for a commercially available basic flux cored wire under steady current conditions are given in Fig. 1. These show that higher deposition rates at given current occur under pulsed conditions and that the process under development can give deposition rates of up to 7 kg of weld metal/hour at usable welding current. The deposition efficiency of the experimental wire was 95 to 97% across the current range.

It should be noted that the Fig. 1 graph of deposition rate against cement applies to any 1.6 mm diameter basic wire embodying the invention under pulse conditions.

A series of experimental wires were formulated to investigate the influence of alloying additions, principally Mn, Ni, Mo, Ti and B, on the all-weld-metal mechanical properties. The Table below gives the nominal deposit compositions aimed for, and classifies the wires according to the general approach used. The weld metal from all wires contained approximately 0.06%C and 0.3 to 0.4% Si.

Wire No.	General Class	Nominal Composition (wt %) Mn	Ni	Mo	Ti	B	Other
1	Not microalloyed	1.5	1.6	0.25	-	-	
2	" "	1.2	1.6	0.25	-	-	
3	" "	1.5	2.2	0.25	-	-	
4	" "	1.2	2.2	0.25	-	-	
5	" "	1.0	3.0	0.25	-	-	
6	Ti addition	1.5	1.6	0.25	0.04	-	
7	" "	1.2	1.6	0.25	0.04	-	
8	" "	1.2	2.2	0.25	0.04	-	
9	" "	1.0	3.0	0.25	0.04	-	
10	Ti + 25 ppm B	1.5	1.6	0.25	0.04	.0025	
11	" " "	1.2	1.6	0.25	0.04	.0025	
12	" " "	1.2	2.2	0.25	0.04	.0025	
13	" " "	1.0	3.0	0.25	0.04	.0025	
14	Ti + 50 ppm B	1.5	1.6	0.25	0.04	.005	
15	" " "	1.2	1.6	0.20	0.04	.005	
16	" " "	1.2	2.2	0.25	0.04	.005	
17	" " "	1.0	3.0	0.25	0.04	.005	
18	Ti + 50 ppm B no Mo	1.5	1.6	-	0.04	.005	
19	" " " "	1.2	1.6	-	0.04	.005	
20	" " " "	1.2	1.6	-	0.04	.005	.01 Al
21	" " " "	1.2	1.6	-	0.04	.005	.02 Al
22	" " " "	1.2	1.6	-	0.04	.005	
23	" " " "	1.0	3.0	-	0.04	.005	

Test plates were welded from each of these wires using the pulse program developed. The parent plate was C-Mn steel (250 Grade) of 19mm thickness while the joint preparation

and interpass temperature were as specified by the American Welding Society (ANSI/AWS A5. 20-79, 1978) for all-weld test plates. Welding was done in the flat position with mechanized travel and a heat input of 1.7 kJ/mm. One all-weld-metal tensile test specimen (50mm gauge length) and three to five Charpy V-notch impact specimens were taken from each test plate. Charpy testing was done at -51°C.

Figure 2 is a schematic representation of the impact and tensile results obtained using the wire numbers from the table. Also marked on this figure are the minimum Charpy values specified and the range of yield strength values specified. This figure illustrates several important features of the results. It is apparent that premium Charpy results, of above say 100J at -51°C, were only obtained with wires microalloyed with Ti and 50 ppm B. These premium Charpy results could be obtained using two distinct Mn-Ni combinations: 1.2% Mn - 1.6% Ni with additions of 0.2% Mo or 0.02% of Al (wires 15 and 21); or 1.0% Mn - 3.0% of Ni with no further addition (wire 23).

The yield strength results show that, of the wires giving premium Charpy values, wires 21 and 23 are within the range specified while wire 15 is marginally too high. Wires 15 and 23 gave 22% tensile elongation while wire 21 gave 26%.

Diffusible hydrogen in weld metal from these wires was found to be 2 to 3 ml/100g of weld metal using the IIW procedure and a gas chromatography measuring system.

Metallographic examination revealed that the as-welded microstructure from wires giving premium impact properties contained at least 90% of fine grained constituents nucleated within prior austenite grains, such as acicular ferrite and intragranular polygonal ferrite.

Based on the all-weld-metal results described above wires 15, 18, 21 and 23 were selected for further assessment. Flat position test plates were welded from 16mm thick HY80 steel using the "groov weld metal test" geometry described in U.S. Military Specification MIL-E-24403/2A (SH), 1983. Heat input was approximately 1.7 kJ/mm. From

these test plates one all-weld tensile specimen, ten Charpy specimens and three dynamic tear specimens were machined. Half of the Charpy specimens were tested at -18°C and half at -51°C while the dynamic tear tests were done at -29°C. The table below lists the average values of the results.

	Tensile		Charpy V-notch		Dynamic Tear
Wire No.	Yield (MPa)	Elongation (%)	Av at -18 (J)	Av at -51°C (J)	Av at -29°C (J)
15	687	24	92	50	419
18	673	22	118	64	584
21	664	23	120	74	528
23	638	23	113	87	676

The yield strengths are considerably increased, by between 35 and 90 MPa, compared to the all-weld-metal results. This is due to incorporation in the weld of alloying elements from the parent plate and, as a result, wires 15, 18 and 21 (marginally) give yield strength values which are too high. Wire 23 has yield strength and elongation properties meeting the requirements of the U.S. Military Specification referred to above. All wires meet the dynamic tear requirements of the U.S. Military Specification.

Overall therefore wire 23, which gives a nominal weld metal composition of 1% Mn, 3% Ni plus microalloying additions of Ti and B, gives welds in HY80 steel having the best strength, elongation and impact properties.

The core composition and specific pulse parameters used for wire 23 are listed below:

Core Composition	% by weight
Iron powder	64.6
Manganese powder	4.1
Ferrosilicon	4.1
Fluorspar	5.3
Marble	4.1
Silica	0.4
Fused mixed oxide	1.0
Nickel powder	13.0
Ferrotitanium	1.0

Iron/Ferroboron agglomerate	2.4

<u>Pulse parameters</u>

Pulse width	3.5 ms
Peak current	520A
Minimum frequency	40 Hz
Maximum frequency	160 Hz
Minimum background current	35A
Maximum background current	35A
Minimum wire speed (m/min)	2.08
Maximum wire speed (m/min)	9.10

It will be appreciated that any combination of pulse parameters which achieve the more general pulse parameters defined above will be satisfactory and will be open to selection by an experienced operator.

The following examples of preferred basic flux wires for joining normal structural steels resulted from the above tests and further experimentation:

<u>Example 2</u>

Wire of 1.6mm diameter with 23% fill for joining normal structural grade steels using Argon - 18% CO_2 shielding gas. (Wire 244, Test plate MI)

<u>Core Composition</u>	% by weight
Iron powder	76.8
Silico manganese	9.8
Ferrosilicon	2.6
Fluorspar	5.3
Marble	4.1
Silica	0.4
Fused mixed oxide	1.0

<u>Pulse parameters</u>

Pulse width	4.8 ms
Peak current	500A
Minimum frequency	37.8 Hz
Maximum frequency	132 Hz
Minimum background current	34A
Maximum background current	40A
Minimum wire speed (m/min)	2.47
Maximum wire speed (m/min)	7.80

Operation

Gives good operation and bead shape over entire range for flat and horizontal welding positions and gives all-position welding capability at low wire feed speeds.

Weld Metal

Composition (wt %)	C	0.09
	Mn	1.24
	Si	0.41

Tensile properties	560 MPa tensile strength, 30% elongation
Impact properties	average of 128J at -20°C in Charpy test
Diffusible hydrogen	less than 3 ml/100g

Example 3

Wire of 1.2mm diameter with 21% fill for joining normal structural grade steels using Argon - 18% CO_2 shielding gas. (Wire 244/9, test plate PT).

Core Composition	% by weight
Iron powder	74.2
Siliso manganese	10.9
Ferrosilicon	2.9
Fluorspar	5.9
Marble	4.6
Silica	0.4
Fused mixed oxide	1.1

Pulse parameters	
Pulse width	2.5 ms
Peak current	480A
Minimum frequency	75 Hz
Maximum frequency	206 Hz
Minimum background current	25A
Maximum background current	25A
Minimum wire speed (m/min)	4.42
Maximum wire speed (m/min)	11.83

Operation

Gives good operation and bead shape over entire range for flat and horizontal welding positions and gives all-position welding at low and intermediat wire speeds.

Weld Metal

Composition (wt %)	C	.09
	Mn	1.40
	Si	0.43

Tensile properties	605 MPa tensile strength, 25% elongation
Impact properties	average of 116J at -20°C in Charpy test
Diffusible hydrogen	less than 3 ml/100g

Example 4 - Pulsed Basic Wire for High Strength Steel.

Wire of 1.6 mm diameter with 23% fill to American Welding Society classification E111T5-K4 for joining high strength steels and using Argon - 18% CO_2 shielding gas (Wire 2106, test plate SN).

Core Composition	% by weight
Iron Powder	60.7
Manganese powder.	6.7
Ferrosilicon	4.5
Fluorspar	5.3
Marble	4.1
Silica	0.4
Fused mixed oxide	1.0
Ferrochromium	0.9
Nickel powder	10.4
Ferromolybdenum	2.1
Ferrotitanium	1.5
Iron/Ferroboron agglomerate	2.4

Pulse parameters

Pulse width	4.8 ms
Peak current	475A
Minimum frequency	37.8 Hz
Maximum frequency	165 Hz
Minimum background current	45A
Maximum background current	45A
Minimum wire speed (m/min)	2.39
Maximum wire speed (m/min)	8.06

Operation

Gives good operation and bead shape over entire range for

flat and horizontal welding positions and gives all-position welding capability at low wire feed speeds.

<u>Weld Metal</u>

Composition (wt %) 0.06% C, 1.49% Mn, 0.39% Si, 2.39% Ni, 0.30% Cr, 0.35% Mo, 0.04% Ti, 0.0066% B.

Tensile properties 711 MPa yield strength,
809 MPa tensile strength,
20% elongation.

Impact properties average of 47J at -51°C in Charpy test

Diffusible hydrogen less than 3 ml/100g

The results show that the combination of basic-flux cored wires and specifically programmed pulse welding provides a versatile welding process with enhanced usability. High deposition downhand welding and an all-position capability can be achieved with a single pulse program by altering the wire feed speed and hence the welding current. Furthermore, the impact and tensile properties obtained from the alloy combination of wire 23 when using this process meet or exceed the requirements of joining HY80 steel. The requirement on diffusible hydrogen level is also readily met.

These results suggest that this combination should be suitable for all-position joining of such steels and of offering considerable advantages over presently available processes.

The principal advantage of the above embodiments compared to conventional basic wire welding is in the improved operating behaviour and bead shape. The basic wire-pulse welding combination allows a much wider range of average welding currents to be used and makes all-position welding with basic wires practical. An example of the extended current range achieved is that, for a 1.6 mm diameter basic wire and pulse welding this range is 130 to 350A whereas, with convention welding the range is 230 to 300A.

This advantage is illustrated in the following example of a test-plate welded in the vertical position using pulse

welding, it being appreciated that it is not practical to produce such a test-plate by conventional means.

Example 5

Wire of 1.2 mm diameter with 21% fill for joining normal structural grade steels using Ar. 18% CO_2 shielding gas (wire 244/9, test-plate LB63.

Core Composition and Pulse Parameters (as in Example 3).

Operation

Good vertical position welding operation illustrated by fact that sound Vee-butt test plate produced to Lloyds Register of Shipping "Approval of Welding Consumables" requirements.

Weld

Composition (wt %)	c	.07
	Mn	1.38
	Si	.51
Impact Properties	average of 96 J at -20°C in Charpy test	
Transverse tensile test	met requirements of Lloyds Register of Shipping.	
Face and Root bend tests	met requirements of Lloyds Register of Shipping.	

In addition to the above described advantages, the basic cored wires contain significantly less slag forming components in the core thereby resulting in less troublesome welding performance while maintaining the necessary quality of the weld.

Tests similar to the above were conducted in relation to various metal cored wires, and the following examples of preferred embodiments resulted:

Examples - Metal Cored Wires

Example 6 - Wire of 1.6mm diameter with 21% fill for joining normal structural grade steels using Argon - 18% CO_2 shielding gas. (Wire 345, Test plate NA).

Core Composition	% by weight
Iron powder	83.2
Manganese powder	7.3
Ferrosilicon	4.4
Silicon powder	1.3

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Ferrotitanium	0.8
Fused mixed oxide	0.4
Ferroboron/iron powder agglomerate	2.6

Pulse parameters

Pulse width	4.5 ms
Peak current	500A
Minimum frequency	40 Hz
Maximum frequency	150 Hz
Minimum background current	33A
Maximum background current	45A
Minimum wire speed (m/min)	2.60
Maximum wire speed (m/min)	8.45

Operation

Very good operation and bead shape over entire range for flat and horizontal welding positions. Has all-position welding capability at lower wire feed speeds.

Weld Metal

Composition (wt %) 0.05C, 1.31 Mn, 0.62Si, 0.04 Ti, 0.0065 B

Tensile properties 598 MPa tensile stength, 24% elongation

Impact properties average of 109J at -20°C in Charpy test

Example 7 - Wire of 1.2mm diameter with 21% fill for joining normal structural grade steels using Argon - 18% CO_2 shielding gas. (Wire 345, Test plate OX).

Core Composition	% by weight
Iron powder	83.5
Manganese powder	7.3
Ferrosilicon	4.4
Silicon powder	1.3
Ferrotitanium	0.8
Fused mixed oxide	0.4
Ferroboron/iron powder agglomerate	2.6

Pulse parameters

Pulse width	2.6 ms
Peak current	400A
Minimum frequency	32 Hz

Maximum frequency	278 Hz
Minimum background current	12A
Maximum background current	78A
Minimum wire speed (m/min)	1.95
Maximum wire speed (m/min)	11.96

<u>Operation</u>

Very good operation and bead shape over entire range for flat and horizontal welding positions plus very good all-position welding capability at low and intermediate wire feed speeds.

<u>Weld Metal</u>

Composition (wt %)	0.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti, 0.0055% B
Tensile properties	589 MPa tensile strength, 23% elongation
Impact properties	average of 123J at -20°C in Charpy test

There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A while, with conventional welding it is 280 to 340A. This could be illustrated using an example, along similar lines to that above for the basic wire, of results from a vertical weld.

The second principal advantage concerns the improved weld mechanical properties obtained. This difference between pulse and conventional metal cored wires is illustrated by the following:

Wire Number	<u>328</u>	<u>345</u>	)see Example
Welding Method	conventional	pulsed	) 6 for details
Test plate type	all weld metal	all weld metal	

Weld Composition (wt%)		
C	0.04	0.05
Mn	1.60	1.31
Si	1.04	0.62
Weld Properties		
Impact (CVN at -20°C)	64 J	109 J
Tensile Strength	622 MPa	598 MPa
Tensil Elongation	23%	24%

The difference in impact properties is most important because it allows the wire/pulse combination to be used in more critical applications. In addition to these advantages, the amounts of manganese and silicon are reduced, thereby improving the mechanical properties of the weld, without compromising the running characteristics and bead shape of the weld.

Example 8 - Pulsed Metal Core Wire for High Strengh Steel

Wire of 1.6 mm diameter with 21% fill to American Welding Society classification E111TG-K3 for joining high strength steels and using Argon - 18% CO_2 shielding gas (Wire 359, test plate UH).

Core Composition	% by weight
Iron powder	65.5
Manganese powder	9.6
Ferrosilicon	3.8
Ferrotitanium	0.8
Silicon powder	1.1
Fused mixed oxide	0.4
Iron/Ferroboron agglomerate	2.6
Nickel powder	12.7
Ferromolybdenum	3.5

Pulse parameters	
Pulse width	5.2 ms
Peak current	460A
Minimum frequency	38 Hz
Maximum frequency	152 Hz
Minimum background current	40A
Maximum background current	40A
Minimum wire speed (m/min)	2.39

Maximum wire speed (m/min) 7.56

Operation

Very good operation and bead shape over entire range for flat and horizontal welding positions. Has all-position welding capability at lower wire feed speeds.

Weld Metal

Composition (wt %) 0.05% C, 1.49% Mn, 0.40% Si, 2.6% Ni, 0.12% Cr, 0.56% Mo, 0.04% Ti, 0.005% B

Tensile properties	686 MPa yield strength, 797 MPa tensile strength, 24% elongation.
Impact properties	average of 41J at -18°C in Charpy test
Diffusible hydrogen	2 to 4 ml/100g

It will be appreciated from the above that the improved cored electrode wires enable pulsed electric arc welding to be performed and result in welds which are superior to welds performed by known cored electrode wires using non-pulsed electric arc welding techniques.

The various components of the core of the wire may be modified without detracting from the advantages provided by the present invention. For example, the various alloying components may be modified to suit the required weld metal properties. Similarly, the components of the fused metal oxide used in each core may be modified to suit the user's requirements provided the core contains sufficient easily ionizable material to result in satisfactory improvement of the weld quality.

CLAIMS:

1. A cored electrode wire for pulsed electric arc welding, characterised in that the slag forming components contained in the core of said electrode wire are of a lower level than the slag forming components which must be contained in a cored wire suitable for normal arc welding.

2. The electrode wire of claim 1, wherein said core includes from 2.5 to 12% calcium fluoride, from 2 to 8% calcium carbonate, from 0.2 to 2% silicon dioxide and from 0.5 to 1.5% of a fused mixed oxide.

3. The electrode wire of claim 1 or 2, wherein said core includes from 2.5 to 8% calcium fluoride, from 2 to 6% calcium carbonate, from 0.2 to 1% silicon dioxide and from 0.75 to 1.25% fused mixed oxide.

4. The electrode wire of claim 3, wherein said fused mixed oxide contains approximately 10% MgO, 15% MnO, 10% Al_2O_3, 5% CaO, 60% SiO_2.

5. A cored electrode wire for pulsed electric arc welding, in which the wire diameter is from 0.9 to 1.8 mm, and the core constitutes from 15 to 28% of the weight of the wire, said core have from 3 to 12% elemental manganese, from 2 to 7% elemental silicon, from 2.5 to 12% calcium fluoride, from 2 to 8% calcium carbonate, from 0.2 to 2% silicon dioxide, from 0.5 to 1.5% fused mixed oxide, from 0 to 1.5% elemental chromium, from 0 to 15% nickel, from 0 to 5% molybdenum, from 0 to 1.5% titanium, from 0 to 0.045% boron, the remainder of the core composition being iron powder.

6. The electrode wire of claim 5, wherein the core comprises from 18 to 25% of the weight of the wire, said core comprising from 5 to 9% elemental manganese, from 2 to 5% elemental silicon, from 2.5 to 8% calcium fluoride, from 2 to 6% calcium carbonate, from 0.2 to 1% silicon dioxide, from 0.75 to 1.25% fused mixed oxide, from 0 to 0.8% titanium, and from 0 to 0.033% boron.

7. The electrode wire of any preceding claim, when used with a pulsed electric arc welding apparatus having the following welding pulse parameters:

Pulse Energy	8 to 250 J
Pulse Frequency	10 to 500 Hz
Background Current	8 to 250 A
Wire Feed Speed	1 to 20 m/min

8. The electrode wire of any preceding claim, when used with a pulsed electric arc welding apparatus having the following welding pulse parameters:

Pulse Energy	10 to 120 J
Pulse Frequency	15 to 350 Hz
Background Current	10 to 100 A
Wire Feed Speed	4 to 17 m/min

9. The electrode wire of claim 7 or 8, wherein the pulse parameters are:

Pulse width (ms)	2 to 6
Peak current (A)	400 to 550
Minimum Pulse Frequency (Hz)	15 to 80
Maximum Pulse Frequency (Hz)	120 to 300
Minimum Background Current (A)	15 to 50
Maximum Background Current (A)	15 to 80
Minimum Wire Speed (m/min)	1.56 to 4.55
Maximum Wire Speed (m/min)	6.50 to 16.90

10. The electrode wire of claim 9, wherein the core composition of the wire and the pulse parameters used are as defined in any one of Examples 1 to 4 of the accompanying specification.

11. A cored electrode wire for use with pulsed electric arc welding, characterised in that the core contains a metal powder composition having less manganese and silicon than would be required for a cored wire for use with normal electric arc welding.

12. The electrode wire of claim 11, wherein said core contains from 4 to 15% elemental manganese and from 2 to 8% elemental silicon, the remainder of the core comprising fused mixed oxide, desired alloying components and iron powder.

13. The electrode wire of claim 12, wherein said core contains from 6 to 9% f elemental manganese and from 2.5 to 5% elemental silicon.

14. The electrode wire of claim 13, wherein said wire has a diameter of from 0.9 to 1.8 mm and the core comprises from 15 to 25% of the weight of the wire, said core composition comprising from 4 to 12% elemental manganese, from 2 to 8% elemental silicon, from 0 to 1% titanium, from 0 to 1.5% fused mixed oxide, from 0 to 0.05% boron, from 0 to 2% elemental chromium, from 0 to 20% nickel, from 0 to 5% molybdenum, the remainder of the core being iron powder.

15. The electrode wire of claim 14, wherein said fused mixed oxide contains approximately 10% MgO, 15% MnO, 10% Al_2O_3, 5% CaO, 60% SiO_2.

16. The electrode wire of any one of claims 9 to 13, when used with a pulsed electric arc welding apparatus having the following pulse parameters:

Pulse Energy	8 to 250 J
Pulse Frequency	10 to 500 Hz
Background Current	8 to 250 A
Wire Feed Speed	1 to 20 m/min

17. The electrode wire of any one of claims 9 to 13, when used with a pulsed electric arc welding apparatus having the following pulse parameters:

Pulse Energy	10 to 120 J
Pulse Frequency	15 to 350 Hz
Background Current	10 to 100 A
Wire Feed Speed	4 to 17 m/min

18. The electrode wire of claim 17, wherein said pulse parameters are:

Pulse width (ms)	2 to 6
Peak current (A)	350 to 550
Minimum Pulse Frequency (Hz)	25 to 100
Maximum Pulse Frequency (Hz)	120 to 350
Minimum Background Current (A)	10 to 50
Maximum Background Current (A)	20 to 100
Minimum Wire Speed (m/min)	1.26 to 3.78
Maximum Wire Speed (m/min)	5.20 to 15.60

19. The electrode wire of claim 18, wherein said core composition and said pulse parameters are as defined in any one of Examples 6 to 8 of the accompanying specification.

20. A method of operating a pulsed electric arc welding apparatus using a cored electrode wire having a basic core composition comprising the steps of adjusting the parameters of the pulse program of the apparatus in accordance with the following:

Pulse Energy	8 to 250 J
Pulse Frequency	10 to 500 Hz
Background Current	8 to 250 A
Wire Feed Speed	1 to 20 m/min

21. The method of claim 20, wherein said pulse parameters are:

Pulse Energy	10 to 120 J
Pulse Frequency	15 to 350 Hz
Background Current	10 to 100 A
Wire Feed Speed	4 to 17 m/min

22. The method of claim 21, wherein said pulse parameters are:

Pulse width (ms)	2 to 6
Peak current (A)	400 to 550
Minimum Pulse Frequency (Hz)	15 to 80
Maximum Pulse Frequency (Hz)	120 to 300
Minimum Background Current (A)	15 to 50
Maximum Background Current (A)	15 to 80
Minimum Wire Speed (m/min)	1.56 to 4.55
Maximum Wire Speed (m/min)	6.50 to 16.90

23. A method of pulsed electric arc welding utilising a cored electrode wire containing a metallic core, characterised in that the electric arc welding apparatus is programmed with the following pulse parameters:

Pulse Energy	8 to 250 J
Pulse Frequency	10 to 500 Hz
Background Current	8 to 250 A
Wire Feed Speed	1 to 20 m/min

24. A method of pulsed electric arc welding utilising a cored electrode wire containing a metallic core, characterised in that the electric arc welding apparatus is programmed with the following pulse parameters:

Pulse Energy	10 to 120 J
Pulse Frequency	15 to 350 Hz
Background Current	10 to 100 A
Wire Feed Speed	4 to 17 m/min

25. A method of pulsed electric arc welding utilising a cored electrode wire containing a metallic core, characterised in that the electric arc welding apparatus is programmed with the following pulse parameters:

Pulse width (ms)	2 to 6
Peak current (A)	350 to 550
Minimum Pulse Frequency (Hz)	25 to 100
Maximum Pulse Frequency (Hz)	120 to 350
Minimum Background Current (A)	10 to 50
Maximum Background Current (A)	20 to 100
Minimum Wire Speed (m/min)	1.26 to 3.78
Maximum Wire Speed (m/min)	5.20 to 15.60

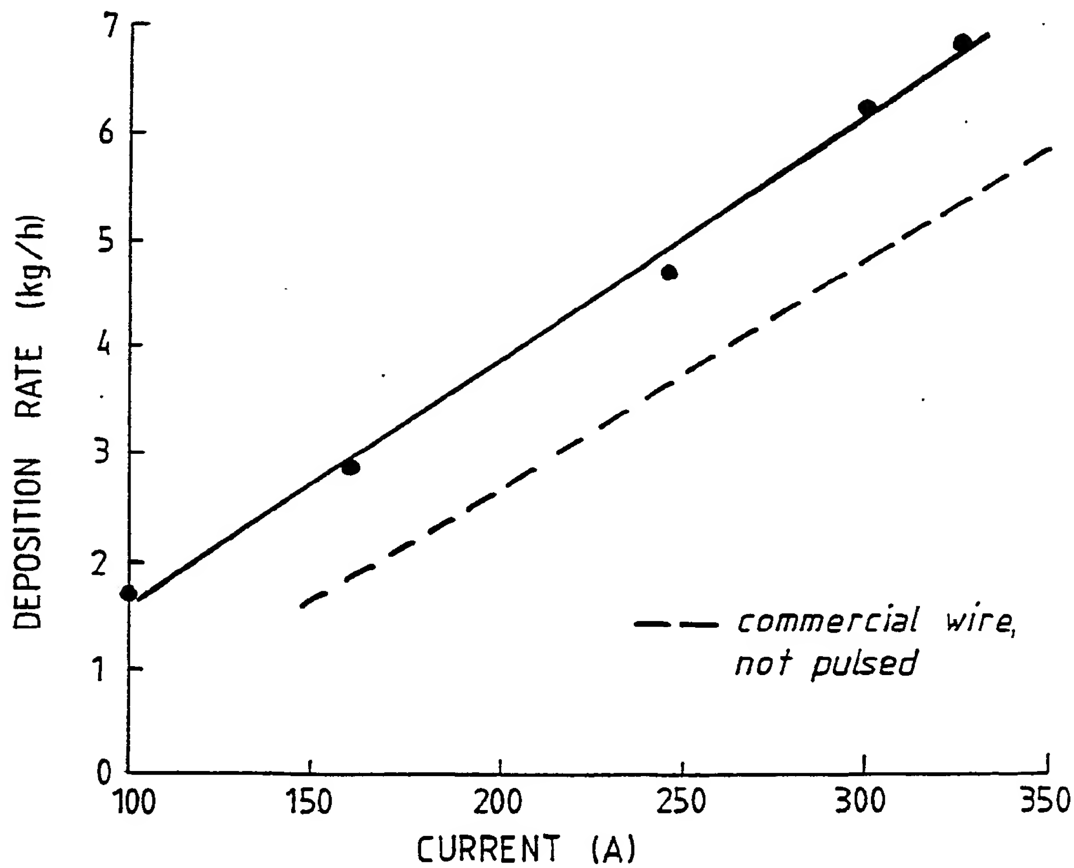
7
6
5
4
3
2
1
0
DEPOSITION RATE (kg/h)
100
150
200
250
300
350
CURRENT (A)
commercial wire,
not pulsed

FIG. 1.

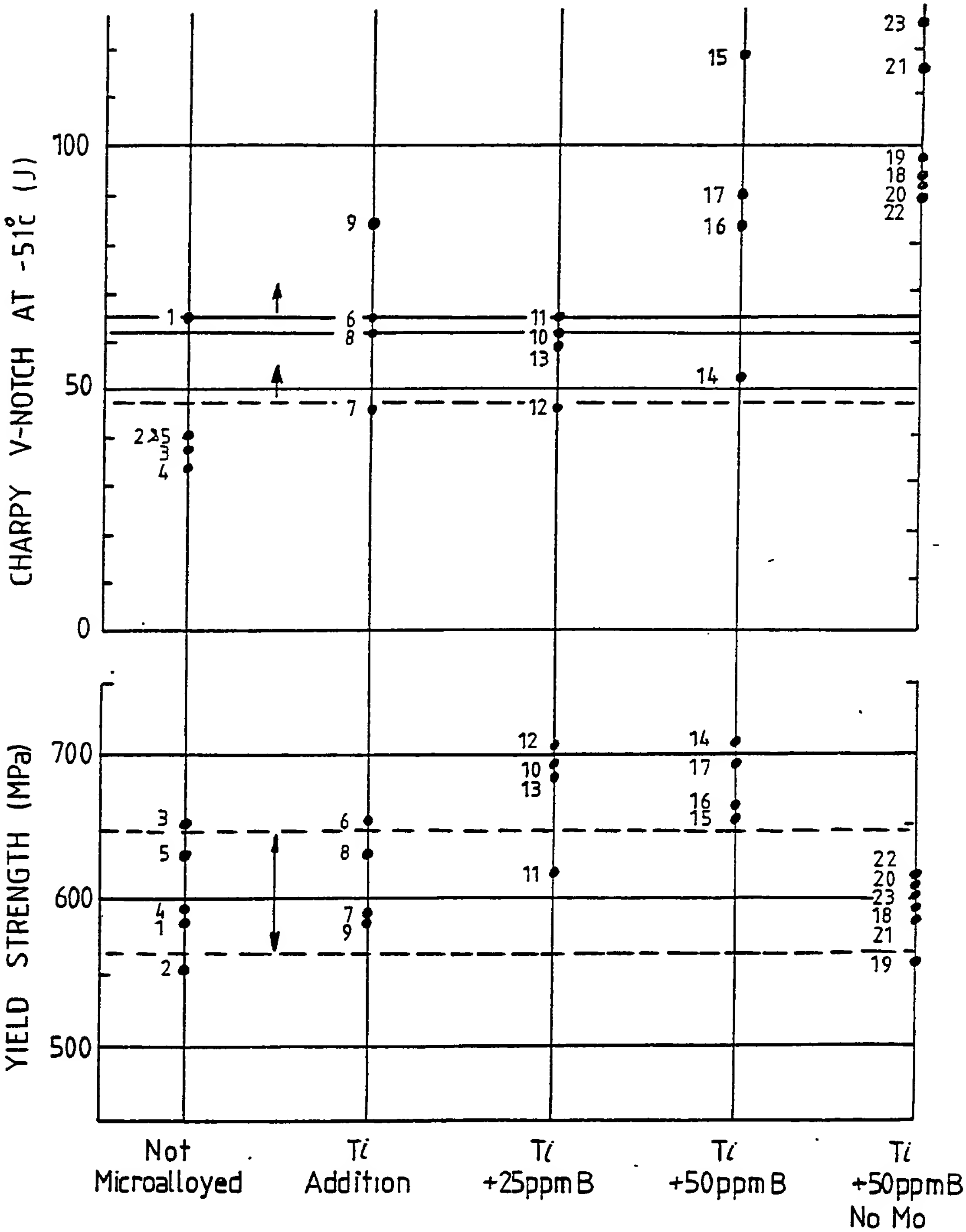
CHARPY V-NOTCH AT -51°C (J)
YIELD STRENGTH (MPa)
100
50
0
700
600
500
Not Microalloyed
Ti Addition
Ti +25ppm B
Ti +50ppm B
Ti +50ppmB No Mo

FIG. 2.

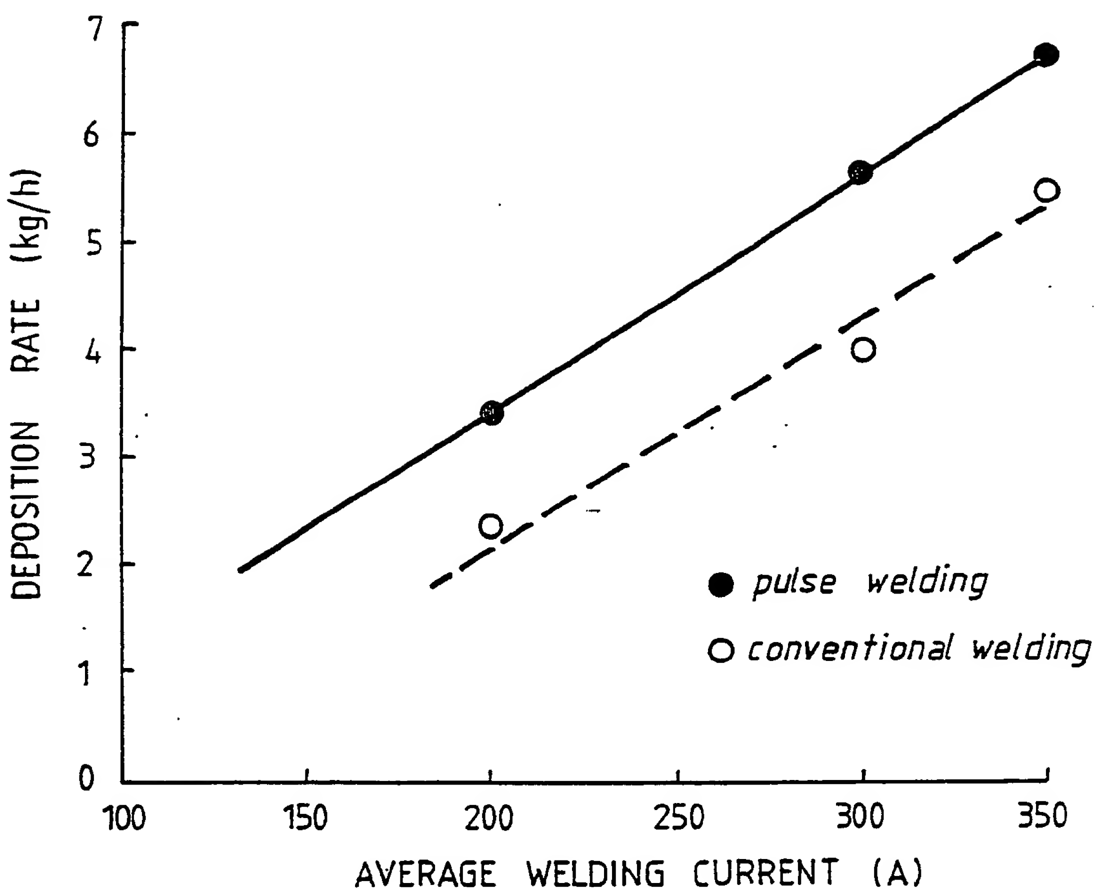
7
6
5
4
3
2
1
0
DEPOSITION RATE (kg/h)
100
150
200
250
300
350
AVERAGE WELDING CURRENT (A)
pulse welding
conventional welding

FIG. 3.

INTERNATIONAL SEARCH REPORT

International Application No PCT/AU 89/00045

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.[4] B23K 35/30, 35/368, 9/09

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	B23K
US Cl.	219/146.52

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

AU : IPC as above, Australian Classification 06.9

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	US,A, 3825721 (CARROLL et al) 23 July 1974 (23.07.74)	(1)
X	US,A, 3787658 (KAMMER et al) 22 January 1974 (22.01.74)	(1,11)
X	US,A, 3702390 (BLAKE et al) 7 November 1972 (07.11.72)	(1-3,11)
X	US,A, 3643061 (DUTTERA et al) 15 February 1972 (15.02.72)	(1,11)
X	US,A, 3504160 (ESSERS et al) 31 March 1970 (31.03.70)	(1,11)
X	Derwent Abstracts Accession No. 83-791687/42 Class P55, JP,A, 58-151993 (NIPPON OILS & FATS KK) 9 September 1983 (09.09.83)	(1-3)
X	AU,B, 17265/70 (439774) (MUREX WELDING PROCESSES LIMITED) 27 August 1973 (27.08.73)	(1,2,11)
X	DE,A1, 3320513 (ESAB AB) 7 June 1983 (07.06.83)	(11,12)

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
15 May 1989 (15.05.89)	24 May 1989 (24.05.89)
International Searching Authority	**Signature of Authorized Officer**
Australian Patent Office	W.J. Major W.J. MAJOR

FURTHER INFORMATI N

VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING (contd)

This International Searching Authority found multiple inventions in this International application as follows:

Claims 1,11 and 20 relate to different aspects of welding with no common unifying feature.

Claim 1 is directed to the slag forming content of a welding electrode.

Claim 11 is directed to the components of a welding electrode relevant to weld bead formation.

Claim 20 is directed to a pulsed arc welding process using any welding electrode.

These aspects are entirely independent and require separate searches.

International Application No. PCT/AU 89/00045

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V.☐ BSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This International search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1.☐ Claim numbers ...., because they relate to subject matter not required to be searched by this Authority, namely:

2.☐ Claim numbers ...., because they relate to parts of the International application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3.☐ Claim numbers........., because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI.☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

See attached Sheet

1.☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers: 1 to 10

4.☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.